IN THE MATTER OF

U.S. Provisional Application No. 60/257,283

By Samsung Electronics Co., Ltd

I, So-hee Kim, an employee of Y.P.Lee & Associates of The Cheonghwa Bldg., 1571-18 Seocho-dong, Seocho-gu, Seoul, Republic of Korea, hereby declare that I am familiar with the Korean and English language and that I am the translator of the U.S. Provisional Application and certify that the following is to the best of my knowledge and belief a true and correct translation

Signed this 11th day of January 2001.

Sohee Kim

ABSTRACT

[Abstract of the Disclosure]

A wearable display system to which a display device for displaying a signal processed in a predetermined way is attached, the wearable display system including a waveguide for propagating a signal output from the display device, a diffraction grating for diffracting a signal passing through the waveguide, and a magnifying glass for allowing a signal, which has diffracted by the diffraction grating and come out of the waveguide, to look magnified to the eye of a user.

A wearable display system according to the present invention uses a minimum number of optical devices, so that it is simply manufactured at a reduced cost, and the volume and weight of a display system are reduced. The use of diffraction gratings contributes to remove chromatic aberration.

[Representative Drawing]

FIG. 5

SPECIFICATION

[Title of the Invention]

A wearable display system

[Brief Description of the Drawings]

FIG. 1 is an exterior view of an example of a head mounted display (HMD).

FIG. 2 is a block diagram of a general HMD.

FIG. 3 is a view illustrating the structure of the optical system in the general HMD of FIG. 2.

FIGS. 4A and 4B illustrate the exterior of a wearable display system according to the present invention.

FIG. 5 shows a wearable display system according to an embodiment of the present invention.

FIG. 6 illustrates the conjugate relationship between diffraction gratings.

FIG. 7A illustrates the principle of diffraction gratings.

FIGS. 7B and 7C shows a transmission diffraction grating and a reflection diffraction grating, respectively.

FIGS. 8A through 8H show all possible embodiments of a wearable display system depending on the type of a diffraction grating and the arrangement of diffraction gratings on a wafer.

FIG. 9 shows a wearable display system according to another embodiment of the present invention.

FIGS. 10A and 10B show other embodiments of a wearable display system in which display panels are attached to both ends of a waveguide.

FIG. 11 shows a wearable display system according to the present invention which adopts a shutter to realize a three-dimensional image.

FIGS. 12A and 12B show applied examples in which a wearable display system according to the present invention controls an inter pupillary distance (IPD).

FIG. 13 illustrates an embodiment of a wearable display system having a monocular structure.

FIGS. 14A through 14H show all possible embodiments of a monocular wearable display system depending on the type of a diffraction grating and the arrangement of diffraction gratings on a wafer.

FIGS. 15A and 15B show monocular wearable display systems according to other embodiments of the present invention.

FIGS. 16A and 16B show aspects in which chromatic aberration is removed by diffraction gratings used in the present invention.

FIGS. 17A through 17C shows types of diffraction gratings capable of being used in the present invention.

FIGS. 18A through 18E show various types of ocular lenses.

FIGS. 19A through 19F show examples of multilayered diffraction gratings.

[Detailed Description of the Invention]

[Object of the Invention]

[Technical field of the Invention and Prior art belonging to the Invention]

The present invention relates to person display systems, and more particularly, to a wearable display system which allows users to see displayed images at a location near to the eye by propagating a display signal via an eyeglass-type or goggle-type optical device.

Optical display systems used for military, medical or personal display, which are generally known as head (helmet) mounted display (HMD) systems, are designed so that users can see a video signal via an eyeglass-type, goggle-type or helmet-type wearing device. This personal display system allows users to receive video information while moving.

FIG. 1 shows the exterior of an example of an HMD. Referring to FIG. 1, the HMD is made up of an eyeglass 100 and an image driving unit 110 attached to the center of the eyeglass. It can be seen from the exterior of this HMD that the image driving unit 110 of this HMD is bulky, heavy and not beautiful. The volume and weight of the image driving unit 110 depend on the number of constituent optical devices.

FIG. 2 shows the structure of a general HMD. In FIG. 2, the HMD includes an image driving unit 200, a display panel 210 and an optical system 220. The image driving unit 200 stores a video signal received from an external source such as a personal computer (not shown) or a video recording/reproducing device (not shown) and processes the received video signal so that the video signal is displayed on the display panel 210 such as a liquid crystal display (LCD) panel. The optical system 220 allows a video signal displayed on the display panel 210 to look as an appropriate-sized virtual image to the eye of a user via its magnifying optical system. An HMD can further include an apparatus for wearing according to the type of its exterior, or include a cable or the like for receiving a video signal or the like from an external source.

FIG. 3 shows the general structure of the optical system 220 in the general HMD of FIG. 2. The conventional optical system is made up of a collimating lens 300, an X prism 310, focusing lenses 320, fold mirrors 330, and eyepieces (or magnifying glasses) 340. The collimating lens 300 collimates light (a video signal) emitted from one point on a display panel or the like. The X prism 310 disperses light received from the collimating lense 300 toward the left and right directions. The focusing lenses 320 are separately installed on both sides of the X prism 310, and focus parallel light transmitted through the X prism 310. The fold mirrors 330 changes the direction of light focused by the focusing lenses 320 so that the light travels toward the human's eye. The eyepieces (or magnifying glasses) 340 allow a small image signal, which has been emitted from a display panel and transmitted through the above optical devices, to appear magnified to the eye of a person. Here, if an image signal to pass through the eyepiece 340 is a color signal, lenses for removing chromatic aberration must be used as the eyepieces 340.

In a general wearable display system referred to as HMD, an optical system is made up of a plurality of optical devices to be precisely designed, namely a collimating lense, an X prism, focusing lenses, fold mirrors and eyepieces, as described above, so that it is difficult to manufacture, thus requiring much effort and a lot of time to manufacture the optical system. Also, even though the lenses and devices have been precisely designed, an addition difficulty in arranging the lenses and devices is provoked. Also, the conventional optical system is bulky and heavy

due to the use of a plurality of optical devices, so that the HMD is difficult for people to wear, and requires a lot of manufacturing costs. Furthermore, a special ocular lens must be separately designed to remove the chromatic aberration of a color signal.

[Technical goal of the Invention]

To solve the above problem, an objective of the present invention is to provide a wearable display system which is simply manufactured with a minimum number of optical devices, removes chromatic aberration using diffraction gratings, and realizes three-dimensional images.

[Structure of the Invention]

The above objective of the present invention is achieved by a wearable display system to which a display panel for displaying a signal processed in a predetermined way is attached, the wearable display system including a waveguide for propagating a signal output from the display panel, a diffraction grating for diffracting a signal passing through the waveguide, and a magnifying glass for allowing a signal, which has diffracted by the diffraction grating and come out of the waveguide, to look magnified to the eye of a user.

Preferably, the waveguide is a medium made of glass.

Preferably, the waveguide is a medium made of plastic.

Preferably, the waveguide is a medium made of acrylic matter (PMMA).

It is preferable that the diffraction grating is made up of a first diffraction grating for reflecting a signal, which has been radiated from the display panel onto the waveguide at a predetermined incidence angle, to both directions of the waveguide at a predetermined reflection angle, and a second diffraction grating for reflecting a signal, which has been received from the waveguide at a predetermined reflection angle, to the waveguide toward the eye of a user at the same angle as the incidence angle of the first diffraction grating.

It is also preferable that the diffraction grating is made up of a first diffraction grating for transmitting a signal, which has been received from the display panel at a predetermined incidence angle, to both directions of the waveguide at a

predetermined transmission angle, and a second diffraction grating for transmitting a signal, which has been propagated on the waveguide and then received from the waveguide at the same angle as the transmission angle of the first diffraction grating, toward the eye of a user at the same angle as the transmission angle of the first diffraction grating.

It is also preferable that the diffraction grating is made up of a first diffraction grating for reflecting a signal, which has been radiated from the display panel onto the waveguide at a predetermined incidence angle, to both directions of the waveguide at a predetermined reflection angle, and a second diffraction grating for transmitting a signal, which has been propagated on the waveguide and then received from the waveguide at the same angle as the predetermined reflection angle of the first diffraction grating, toward the eye of a user at the same angle as the reflection angle of the first diffraction grating.

It is also preferable that the diffraction grating is made up of a first diffraction grating for transmitting a signal, which has been received from the display panel at a predetermined incidence angle, to both directions of the waveguide at a predetermined transmission angle, and a second diffraction grating for reflecting a signal, which has been propagated on the waveguide and then received from the waveguide at the same angle as the predetermined transmission angle of the first diffraction grating, toward the eye of a user at the same angle as the incidence angle of the first diffraction grating.

Preferably, the diffraction grating is incorporated into the waveguide.

Preferably, the magnifying glass is incorporated into the waveguide.

Preferably, the diffraction grating and the magnifying glass are incorporated into the waveguide.

Preferably, the diffraction grating is formed by hologram.

Hereinafter, the present invention will be described in detail with reference to the attached drawings.

FIGS. 4A and 4B are a front side view and an upper side view of a wearable display system according to the present invention, respectively. Referring to FIGS. 4A and 4B, the wearable display system has a simple structure in which a lens 400

and a display panel 410 are combined. The wearable display system according to the present invention can be light and small due to the use of a diffraction grating and a magnifying glass, compared to a conventional one. According to the present invention, a display system capable of being simply worn like an eyeglass can be realized, instead of a display system that is bulky and heavy like an existing HMD such as a helmet type display system. Also, a module-type wearable display system is manufactured and used by detachably attaching the module to an existing eyeglass or the like. FIGS. 4A and 4B show an example among various possible exteriors of a wearable display system. A variety of light and small wearable display systems can be realized.

A wearable display system according to the present invention can be a binocular display system designed so that a user can see a displayed image using his or her both eyes, or a monocular display system designed so that a user can view a displayed image using an eye of his or hers. A binocular display system provides three-dimensional (3D) display, which will be described later in detail.

First, a binocular wearable display system will now be described.

FIG. 5 shows a wearable display system according to an embodiment of the present invention. The wearable display system includes a display panel 500, a waveguide 510, first, second and third diffraction gratings 520, 522 and 524 and magnifying glasses 530. The display panel 500 displays a video signal received from a signal source (not shown) via wire or radio (not shown). The waveguide 510, which is formed within the lens 400 of FIG. 4, propagates the video signal emitted from the display panel 500. The first, second and third diffraction gratings 520, 522 and 524 diffract a signal passing through the waveguide so that the signal finally heads for human's eyes. The magnifying glasses 530 and 532 magnify a video signal, which comes out of the waveguide 510 and enters into the human's eyes.

In the principle of the wearable display system of FIG. 5, an object within the focal distance, **f**, of a lens looks magnified to the human's eye. The focal distance **f** of the lens can be determined according to the size of an object and the size of a magnified image. In FIG. 5, when light from the display panel is incident upon the waveguide 510 at a predetermined incidence angle, the diffraction grating 520, installed opposite to the waveguide on which light is incident, bends the direction of

the incident light to both directions of the waveguide so that the incident light has an internal total reflection angle θ within the waveguide. The internal total reflection angle θ is calculated by Equation 1:

$$\theta = \sin^{-1}\left(\frac{1}{n}\right) \qquad \text{...(1)}$$

wherein the numerator of a fraction is set to be the refractive index of air, that is, 1.

The path of light traveling within the waveguide must be shorter than the focal distance **f** of the magnifying glass 530 in front of the eye of a person. For example, if the refractive index of the waveguide is **n**, and the thickness thereof is **t**, **n×t** must be shorter than the focal distance **f** of the magnifying glass 530. The type and thickness of the waveguide and the number of times of reflection performed within the waveguide are determined by the focal distance **f** of the magnifying glass 530. However, the focus and size of the magnifying glass 530 must be preferentially determined in consideration of the size of the display panel 500 and the size of a magnified image that is adequate for the purpose of use of a wearable display system NED. This determination helps designing of the total structure of the NED, and, accordingly, the type and thickness of a waveguide and the number of times of reflection are determined.

The first and second diffraction gratings 520 and 522 are in a conjugate relationship, and the first and third diffraction gratings 520 and 524 are in a conjugate relationship. If the diffraction angle of light incident upon the first diffraction grating 520 at a predetermined incidence angle is θ, the second and third diffraction gratings 522 and 524 diffract light at the same angle as the incidence angle of the first diffraction grating 52 when the incidence angles of light incident upon the second and third diffraction gratings 522 and 524 are the same as that of the first diffraction grating 520, θ. The second and third diffraction gratings 522 and 524 are the same. The embodiment of FIG. 5 refers to a wearable display system having one display panel and three diffraction gratings, but the number of diffraction gratings and the number of display panels in the present invention cannot be limited to a specific number.

FIG. 6 illustrates the conjugate relationship between diffraction gratings. First and second diffraction gratings 600 and 610 have the same grating intervals **d**, and must be parallel to a waveguide.

FIG. 7A is a view for explaining the principle of diffraction of a diffraction grating. Equation 2 is obtained using an incidence angle θ_i, a diffraction angle θ_d and a grating interval **d**:

$$(\sin\theta_d - \sin\theta_i) = m\frac{\lambda}{d} \qquad \text{...(2)}$$

wherein m denotes the diffraction order, and λ denotes the wavelength of incident light. The angle of diffraction can be controlled differently depending on the shape and characteristics of a diffraction grating. Here, if light diffracted by a diffraction grating is propagated into a waveguide, the diffraction angle of the light must satisfy the condition of an internal total reflection angle.

FIGS. 7B and 7C show a transmission diffraction grating and a reflection diffraction grating, respectively. The transmission diffraction grating of FIG. 7B bends incident light by θ and transmits the light in both directions. Light diffracted to the left is expressed as +1, and light diffracted to the right is expressed as −1. Here, the sign denotes the left or right direction, and "1" denotes a diffraction order 1. The reflection diffraction grating of FIG. 7C reflects incident light by θ in both directions.

FIG. 8A shows the structure of a wearable display system having a display panel 802 and first, second and third diffraction gratings 804, 806 and 808 located on the side of a waveguide 800 opposite to the side near the eye of a person. Light from the display panel 802 is incident upon the first diffraction grating 804 at a predetermined incidence angle and transmitted thereby to the left and right directions within the waveguide at predetermined angles. The light transmitted within the waveguide 800 is propagated in the left and right directions of the waveguide and then is incident upon the second and third diffraction gratings 806 and 808, which are the conjugates of the first diffraction grating 804, at the same angle as the transmission angle of the first diffraction grating 804. Light incident upon the second and third diffraction gratings 806 and 808 are reflected by the same angle as the incidence angle of the first diffraction grating 804 toward the eye

of a person. Magnifying glasses are located at the left and right of the side of the waveguide 800 which reflected light reaches, so that a user can view a magnified image of a video signal through the magnifying glasses. In this embodiment, the first diffraction grating 804 is of transmission type, and the second and third diffraction gratings 806 and 808 are of reflection type.

FIG. 8B shows the structure of a wearable display system in which a display panel 812 is on the side of a waveguide 810 opposite to the side near the eye of a person, and first, second and third diffraction gratings 814, 816 and 818 are installed on the side of the waveguide 810 near the eye of a person. Light, which is emitted from the display panel 812 and is incident upon the first diffraction grating 814 via the waveguide 810 at a predetermined incidence angle, is reflected in the left and right directions at predetermined angles. The reflected light is propagated within the waveguide and then is incident upon the second and third diffraction gratings 816 and 818, which are the conjugates of the first diffraction grating 814, at the same angle as the reflection angle of the first diffraction grating 814. The incident light is transmitted by the second and third diffraction gratings 816 and 818 at the same angle as the incidence angle of the first diffraction grating 814 and propagated toward the eye of a person. Magnifying glasses are attached to the second and third diffraction gratings 816 and 818, and magnify a transmitted signal. In this embodiment, the first diffraction grating 814 is of reflection type, and the second and third diffraction gratings 816 and 818 are of transmission type.

FIG. 8C shows the structure of a wearable display system in which a display panel 822 is on the side of a waveguide 820 near the eye of a person, and first, second and third diffraction gratings 824, 826 and 828 are installed on the side of the waveguide 800 opposite to the side near the eye of a person. Light, which is emitted from the display panel 822 and is incident upon the first diffraction grating 824 via the waveguide 820 at a predetermined incidence angle, is reflected by the first diffraction grating 824 in the left and right directions at predetermined angles. The reflected light is propagated in the left and right directions of the waveguide 820 and then is incident upon the second and third diffraction gratings 826 and 828, which are the conjugates of the first diffraction grating 824, at the same angle as the reflection angle of the first diffraction grating 824. The incident light is reflected by

the second and third diffraction gratings 826 and 828 at the same angle as the incidence angle of the first diffraction grating 824 and propagated toward the eye of a person. Magnifying glasses are installed at the left and right on the side of the waveguide 820 that the reflected light reaches, and allow a user to view a magnified image of a video signal. In this embodiment, the first, second and third diffraction gratings 824, 826 and 828 are all reflection diffraction gratings.

FIG. 8D shows the structure of a wearable display system having a display panel 832 and first, second and third diffraction gratings 834, 836 and 838 located on the side of a waveguide 830 near the eye of a person. Light of a video signal, which is emitted from the display panel 832 and is incident upon the first diffraction grating 814 at a predetermined incidence angle, is transmitted by the first diffraction grating 814 to the left and right directions within the waveguide 830 at predetermined angles. The transmitted light is propagated within the waveguide 830 and then is incident upon the second and third diffraction gratings 836 and 838, which are the conjugates of the first diffraction grating 834, at the same angle as the transmission angle of the first diffraction grating 834. The incident light is transmitted by the second and third diffraction gratings 836 and 838 at the same angle as the incidence angle of the first diffraction grating 834, and propagates toward the eye of a person. Magnifying glasses are attached to the second and third diffraction gratings 836 and 838, and magnify a transmitted signal.. In this embodiment, the first, second and third diffraction gratings 834, 816 and 818 are all transmission diffraction gratings.

FIG. 8E shows the structure of a wearable display system in which a display panel 842 and second and third diffraction gratings 846 and 848 are on the side of a waveguide 840 opposite to the side near the eye of a person, and a first diffraction grating 844 is installed on the side of the waveguide 840 near the eye of a person. Light, which is emitted from the display panel 842 and is incident upon the first diffraction grating 844 via the waveguide 840 at a predetermined incidence angle, is reflected by the first diffraction grating 844 in the left and right directions at predetermined angles. The reflected light is propagated in the left and right directions of the waveguide 840 and then is incident upon the second and third diffraction gratings 846 and 848, which are the conjugates of the first diffraction

grating 844, at the same angle as the reflection angle of the first diffraction grating 844. The incident light is reflected by the second and third diffraction gratings 846 and 848 at the same angle as the incidence angle of the first diffraction grating 844 and propagated toward the eye of a person. Magnifying glasses are installed at the left and right on the side of the waveguide 840 that the reflected light reaches, and allow a user to view a magnified image of a video signal. In this embodiment, the first, second and third diffraction gratings 844, 846 and 848 are all reflection diffraction gratings.

FIG. 8F shows the structure of a wearable display system in which a display panel 852 and a first diffraction grating 854 are installed on the side of a waveguide 850 opposite to the side near the eye of a person, and second and third diffraction gratings 856 and 858 are installed on the side of a waveguide 850 near the eye of a person. Light of a video signal, which is emitted from the display panel 852 and is incident upon the first diffraction grating 854 at a predetermined incidence angle, is transmitted by the first diffraction grating 854 to the left and right directions within the waveguide 850 at predetermined angles. The transmitted light is propagated within the waveguide 850 and then is incident upon the second and third diffraction gratings 856 and 858, which are the conjugates of the first diffraction grating 854, at the same angle as the transmission angle of the first diffraction grating 854. The incident light is transmitted by the second and third diffraction gratings 856 and 858 at the same angle as the incidence angle of the first diffraction grating 854, and propagates toward the eye of a person. Magnifying glasses are attached to the second and third diffraction gratings 856 and 858, and magnify a transmitted signal. In this embodiment, the first, second and third diffraction gratings 854, 856 and 858 are all transmission diffraction gratings.

FIG. 8G shows the structure of a wearable display system in which a display panel 862 and second and third diffraction gratings 866 and 868 are installed on the side of a waveguide 860 near the eye of a person, and a first diffraction grating 864 is installed on the side of the waveguide 860 opposite to the side near the eye of a person. Light, which is emitted from the display panel 862 and is incident upon the first diffraction grating 864 via the waveguide 860 at a predetermined incidence angle, is reflected by the first diffraction grating 864 to the left and right directions at

predetermined angles. The reflected light is propagated within the waveguide 860 and then is incident upon the second and third diffraction gratings 866 and 868, which are the conjugates of the first diffraction grating 864, at the same angle as the reflection angle of the first diffraction grating 864. The incident light is transmitted by the second and third diffraction gratings 866 and 868 at the same angle as the incidence angle of the first diffraction grating 864, and propagates toward the eye of a person. Magnifying glasses are attached to the second and third diffraction gratings 866 and 868, and magnify a transmitted signal. In this embodiment, the first diffraction grating 864 is a reflection diffraction grating, and the second and third diffraction gratings 866 and 868 are transmission diffraction gratings.

FIG. 8H shows the structure of a wearable display system in which a display panel 872 and a first diffraction grating 874 are on the side of a waveguide 870 near the eye of a person, and second and third diffraction gratings 876 and 878 are installed on the side of the waveguide 870 opposite to the side near the eye of a person. Light, which is emitted from the display panel 872 and is incident upon the first diffraction grating 874 at a predetermined incidence angle, is transmitted by the first diffraction grating 874 in the left and right directions within the waveguide 870 at predetermined angles. The transmitted light is propagated in the left and right directions within the waveguide 870 and then is incident upon the second and third diffraction gratings 876 and 878, which are the conjugates of the first diffraction grating 874, at the same angle as the transmission angle of the first diffraction grating 874. The incident light is reflected by the second and third diffraction gratings 876 and 878 at the same angle as the incidence angle of the first diffraction grating 874 and propagated toward the eye of a person. Magnifying glasses are installed at the left and right on the side of the waveguide 870 that the reflected light reaches, and allow a user to view a magnified image of a video signal. In this embodiment, the first diffraction grating 874 is a transmission diffraction grating, and the second and third diffraction gratings 876 and 878 are reflection diffraction gratings.

As described above, it can be seen that various types of wearable display systems can be realized depending on the arrangement of a display panel and diffraction gratings on the basis of a waveguide. As shown in FIGS. 8A, 8B, 8E and

8F, it is preferable that a display panel is located on the side of a waveguide opposite to the side near the eye of a person.

FIG. 9 shows a wearable display system adopting two display panels, according to another embodiment of the present invention. In this wearable display system, display panels 920 and 922 are located on the bottom of the left and right ends of a waveguide 924, respectively, not on the center portion of the waveguide 924. First diffraction gratings 926 and 928 are parallel to the display panels 920 and 922, respectively. Second diffraction gratings 930 and 932, which are the conjugates of the first diffraction gratings 926 and 928, are installed on the side of the waveguide 924 opposite to the side near the eye of a person. Light of a video signal from the display panels 920 and 922 is incident upon the first diffraction gratings 926 and 928, respectively, and transmitted thereby to the waveguide at a predetermined angle. The transmitted light is incident upon the second diffraction gratings 930 and 932 at the same angle as the transmission angle. Light incident upon the second diffraction gratings 930 and 932 is reflected at the same angle as the incidence angle of the first diffraction grating to the waveguide 924 so that the reflected light heads for the eye of a person. Magnifying glasses (not shown) are installed on the surface of the waveguide that the reflected light reaches, and magnify an image. In this embodiment, the first diffraction gratings 926 and 928 are transmission diffraction gratings, and the second diffraction gratings 930 and 932 are reflection diffraction gratings. Many different structures can be created by combining the components included in the embodiment of FIG. 9 into many cases as in FIGS. 8A through 8H where the types and positions of diffraction gratings and the position of a display panel are variously combined. FIGS. 8A through 8H and 9 illustrate combinations in the case that a display system is made up of one or two display panels and a predetermined number of diffraction gratings that are adequate for the number of display panels. However, the number of display panels and the number of diffraction gratings can be increased at designer's request. In this case, many different structures can be created by variously combining the types and positions of diffraction gratings and the positions of display panels as shown in FIGS. 8A through 8H.

FIG. 10A shows still another embodiment of a wearable display system in which a display panel is attached at either end of a waveguide. In this embodiment, display panels 1000 and 1002 are located on the flank of the left and right ends of a waveguide 1004, respectively, not on the center portion of the waveguide 1004. First diffraction gratings 1006 and 1008 are parallel to the display panels 1000 and 1002, respectively. Second diffraction gratings 1010 and 1012, which are the conjugates of the first diffraction gratings 1006 and 1008, are installed on the side of the waveguide 1004 opposite to the side near the eye of a person. Light of a video signal from the display panels 1000 and 1002 is incident upon the first diffraction gratings 1006 and 1008, respectively, and transmitted thereby into the waveguide at a predetermined angle. The transmitted light is incident upon the second diffraction gratings 1010 and 1012 at the same angle as the transmission angle. Light incident upon the second diffraction gratings 1010 and 1012 is reflected at the same angle as the incidence angle of the first diffraction gratings on the basis of the waveguide 1004 so that the reflected light heads for the eye of a person. Magnifying glasses (not shown) are installed on the surface of the waveguide that the reflected light reaches, and magnify an image. Here, the first diffraction gratings 1006 and 1008 are transmission diffraction gratings, and the second diffraction gratings 1010 and 1012 are reflection diffraction gratings.

FIG. 10B shows an embodiment of a wearable display system in which the structure is the same as that of FIG. 10A but different types of diffraction gratings are adopted. Also, in this embodiment, display panels 1020 and 1022 are located on the flank of the left and right ends of a waveguide 1024, respectively, not on the center portion of the waveguide 1024. First diffraction gratings 1026 and 1028 are parallel to the display panels 1020 and 1022, respectively. Second diffraction gratings 1030 and 1032, which are the conjugates of the first diffraction gratings 1026 and 1028, are installed on the side of the waveguide 1024 near the eye of a person. Light of a video signal from the display panels 1020 and 1022 is incident upon the first diffraction gratings 1026 and 1028, respectively, and transmitted thereby into the waveguide at a predetermined angle. The transmitted light is incident upon the second diffraction gratings 1030 and 1032 at the same angle as the transmission angle. Light incident upon the second diffraction gratings 1030

and 1032 is transmitted at the same angle as the incidence angle of the first diffraction gratings on the basis of the waveguide 1024 so that the transmitted light heads for the eye of a person. The transmitted light looks magnified to the eye of a person through magnifying glasses (not shown) attached at the outer side of the second diffraction gratings 1030 and 1032. Here, the first diffraction gratings 1026 and 1028 and the second diffraction gratings 1030 and 1032 are transmission diffraction gratings.

FIG. 11 shows a wearable display system according to the present invention which adopts a shutter to realize a three-dimensional image. The example of FIG. 11 is a three-dimensional image implementation example with respect to the case of FIG. 8E. The use of a shutter is applicable to all types of wearable display systems having the above-described structures. Here, shutters 1100 and 1110 for blocking light propagated in two directions of a waveguide are alternately opened or closed at different times, so that the same image reaches both eyes of a person with a time difference, resulting in an effect that an image looks three-dimensional. Though not shown in the attached drawings, a wearable display system adopting a shutter at only one side of the right and left sides can derive the same effect as described above.

As described above, a three-dimensional image can be achieved when the same image reaches both eyes of a person with a time difference. Hence, in many cases such as when media having different refractive indices are used as right and left waveguides to which light is propagated, when diffraction gratings on the right and left sides have different grating intervals, or when a different number of diffraction gratings are located on the right and left sides, the propagation distance of light on the right side is different from that on the left side due to the formation of a difference in refraction angle between the right and left sides. Also, a final signal enters in both eyes of a person with a time difference, so that a three-dimensional image is formed. When different media waveguides are adopted on the right and left sides, second and third diffraction gratings must be designed in consideration of the diffraction angles of light incident upon the first diffraction gratings that are different on the right and left sides depending on the type of media. Also, when the number of diffraction gratings on the right side is different from that on the left side,

diffraction gratings must be designed in consideration of the diffraction angle. Here, selection of a waveguide medium and designing of diffraction gratings must be performed on the assumption that the diffraction angle is the angle where internal total reflection is accomplished.

FIG. 12A shows an applied example in which a wearable display system according to the present invention controls an inter pupillary distance (IPD). Most adult men and women have the IPD having a range of 50 to 74mm. If a person wears a wearable display system having an IPD that is different to his or her IPD, first, a right and a left image appear to be misaligned with each other, and finally they are naturally overlapped into a single image. However, this case further increases the fatigue of the eye than the case when the IPD of a wearable display system is adjusted to the IPD of the person. Hence, the IPD of a wearable display system can be controlled by moving magnifying glasses 1200 and 1210 to face the pupils of a person, so that the person can see a clear image. FIG. 12B shows an embodiment in which a waveguide 1230 and eyepieces 1200 and 1210 are manufactured in a saw tooth shape to be able to be combined and moved, so that a user can move the magnifying glasses 1200 and 1210 by a certain distance on the waveguide 1230.

FIG. 13 illustrates an embodiment of a wearable display system having a monocular structure. A monocular display system has the same structure and the same principle as the binocular display system of FIG. 5, except it uses only one eye of a person. The monocular display system includes a display panel 1300, a waveguide 1310, first and second diffraction gratings 1320 and 1330 and an eyepiece 1340. The display panel 1300 displays a video signal received from a predetermined signal source (not shown) via a wire or radio (not shown). The waveguide 1310 propagates the video signal from the display panel 1300 in one direction. The first and second diffraction gratings 1320 and 1330 diffract a signal passing through the waveguide 1310 so that the signal finally heads for the eye of a person. The first and second diffraction gratings 1320 and 1330 have a conjugate relationship, which means that, when light (a signal) is incident upon the first diffraction grating 1320 at a predetermined incidence angle and diffracted thereby at a predetermined angle, it is propagated on the waveguide 1310 and then is incident

upon the second diffraction grating 1322 at the same angle of the diffraction angle of the first diffraction grating 1320 and diffracted by the second diffraction grating 1322 at the same angle as the incidence angle of the first diffraction grating 1320. The magnifying glass 1340 magnifies a video signal from the waveguide 1310 so that the video signal look magnified to a user.

FIGS. 14A through 14H show all possible embodiments of a monocular wearable display system depending on the types of diffraction gratings and the arrangement of the diffraction gratings on a wafer.

FIG. 14A shows the structure of a monocular wearable display system having a display panel 1402 and first and second diffraction gratings 1404 and 1406 located on the side of a waveguide 1400 opposite to the side near the eye of a person. Light from the display panel 1402 is incident upon the first diffraction grating 1404 at a predetermined incidence angle and transmitted thereby in the left direction within the waveguide at a predetermined angle. The light transmitted within the waveguide 1400 is propagated in the left direction of the waveguide and then is incident upon the second diffraction grating 1406, which is the conjugate of the first diffraction grating 1404, at the same angle as the transmission angle of the first diffraction grating 1404. Light incident upon the second diffraction grating 1406 is reflected at the same angle as the incidence angle of the first diffraction grating 1404 toward the eye of a person. A magnifying glass is located on the side of the waveguide 1400 which reflected light reaches, so that a user can view a magnified image of a video signal through the magnifying glass. In this embodiment, the first diffraction grating 1404 is a transmission diffraction grating, and the second diffraction grating 1406 is a reflection diffraction grating.

FIG. 14B shows the structure of a monocular wearable display system in which a display panel 1412 is on the side of a waveguide 1410 opposite to the side near the eye of a person, and first and second diffraction gratings 1414 and 1416 are installed on the side of the waveguide 1410 near the eye of a person. Light, which is emitted from the display panel 1412 and is incident upon the first diffraction grating 1414 via the waveguide 1410 at a predetermined incidence angle, is reflected in the left direction at a predetermined angle. The reflected light is propagated within the waveguide 1410 and then is incident upon the second

diffraction grating 1416, which is the conjugate of the first diffraction grating 1414, at the same angle as the reflection angle of the first diffraction grating 1414. The incident light is transmitted by the second diffraction grating 1416 at the same angle as the incidence angle of the first diffraction grating 1414 and propagated toward the eye of a person. A magnifying glass is attached to the second diffraction grating 1416, and magnifies a transmitted signal. In this embodiment, the first diffraction grating 1414 is a reflection diffraction grating, and the second diffraction grating 1416 is a transmission diffraction grating.

FIG. 14C shows the structure of a monocular wearable display system in which a display panel 1422 is located on the side of a waveguide 1420 near the eye of a person, and first and second diffraction gratings 1424 and 1426 are located on the side of a waveguide 1420 opposite to the side near the eye of a person. Light, which is emitted from the display panel 1422 and is incident upon the first diffraction grating 1424 at a predetermined incidence angle via the waveguide 1420, is reflected by the first diffraction grating 1424 in the left direction at a predetermined angle. The reflected light is propagated in the left direction of the waveguide 1420 and then is incident upon the second diffraction grating 1426, which is the conjugate of the first diffraction grating 1424, at the same angle as the reflection angle of the first diffraction grating 1424. Light incident upon the second diffraction grating 1426 is reflected at the same angle as the incidence angle of the first diffraction grating 1424 toward the eye of a person. A magnifying glass is located on the side of the waveguide 1420 which reflected light reaches, so that a user can view a magnified image of a video signal through the magnifying glass. In this embodiment, the first and second diffraction gratings 1424 and 1426 are reflection diffraction gratings.

FIG. 14D shows the structure of a monocular wearable display system in which a display panel 1432 and first and second diffraction gratings 1434 and 1436 are installed on the side of the waveguide 1430 near the eye of a person. Light of a video signal, which is emitted from the display panel 1432 and is incident upon the first diffraction grating 1414 at a predetermined angle, is transmitted in the left direction within the waveguide 1430 at a predetermined angle. The transmitted light is propagated within the waveguide 1430 and then is incident upon the second diffraction grating 1436, which is the conjugate of the first diffraction grating 1434, at

the same angle as the transmission angle of the first diffraction grating 1434. The incident light is transmitted by the second diffraction grating 1436 at the same angle as the incidence angle of the first diffraction grating and propagated toward the eye of a person. A magnifying glass is attached to the second diffraction grating 1436, and magnifies a transmitted signal. In this embodiment, the first and second diffraction grating 1434 and 1436 are transmission diffraction gratings.

FIG. 14E shows the structure of a monocular wearable display system in which a display panel 1442 and a second diffraction grating 1446 are located on the side of a waveguide 1440 opposite to the side near the eye of a person, and a first diffraction grating 1444 is located on the side of the waveguide 1440 near the eye of a person. Light, which is emitted from the display panel 1442 and is incident upon the first diffraction grating 1444 via the waveguide 1440 at a predetermined incidence angle, is reflected by the first diffraction grating 1444 in the left direction at a predetermined angle. The reflected light is propagated in the left direction of the waveguide 1440 and then is incident upon the second diffraction grating 1446, which is the conjugate of the first diffraction grating 1444, at the same angle as the reflection angle of the first diffraction grating 1444. The incident light is reflected by the second diffraction grating 1446 at the same angle as the incidence angle of the first diffraction grating 1444 toward the eye of a person. A magnifying glass is located on the side of the waveguide 1440 which reflected light reaches, so that a user can view a magnified image of a video signal through the magnifying glass. In this embodiment, the first and second diffraction gratings 1444 and 1446 are reflection diffraction gratings.

FIG. 14F shows the structure of a monocular wearable display system in which a display panel 1452 and a first diffraction grating 1454 are on the side of a waveguide 1450 opposite to the side near the eye of a person, and a second diffraction gratings 1456 is installed on the side of the waveguide 1450 near the eye of a person. Light of a video signal, which is emitted from the display panel 1452 and is incident upon the first diffraction grating 1454 at a predetermined incidence angle, is transmitted in the left direction within the waveguide 1450 at a predetermined angle. The transmitted light is propagated within the waveguide 1450 and then is incident upon the second diffraction grating 1456, which is the

conjugate of the first diffraction grating 1454, at the same angle as the transmission angle of the first diffraction grating 1454. The incident light is transmitted by the second diffraction grating 1456 at the same angle as the incidence angle of the first diffraction grating and propagated toward the eye of a person. A magnifying glass is attached to the second diffraction grating 1456, and magnifies a transmitted signal. In this embodiment, the first and second diffraction gratings 1454 and 1456 are transmission diffraction gratings.

FIG. 14G shows the structure of a monocular wearable display system in which a display panel 1462 and a second diffraction grating 1466 are on the side of a waveguide 1460 near the eye of a person, and a first diffraction gratings 1464 is installed on the side of the waveguide 1460 opposite to the side near the eye of a person. Light, which is emitted from the display panel 1462 and is incident upon the first diffraction grating 1464 via the waveguide 1460 at a predetermined incidence angle, is reflected in the left direction at a predetermined angle. The reflected light is propagated within the waveguide 1460 and then is incident upon the second diffraction grating 1466, which is the conjugate of the first diffraction grating 1464, at the same angle as the reflection angle of the first diffraction grating 1464. The incident light is transmitted by the second diffraction grating 1466 at the same angle as the incidence angle of the first diffraction grating and propagated toward the eye of a person. A magnifying glass is attached to the second diffraction grating 1466, and magnifies a transmitted signal. In this embodiment, the first diffraction grating 1464 is a reflection diffraction grating, and the second and third diffraction gratings 1466 and 1468 are transmission diffraction gratings.

FIG. 14H shows the structure of a monocular wearable display system in which a display panel 1472 and a first diffraction grating 1474 are located on the side of a waveguide 1470 near the eye of a person, and a second diffraction grating 1476 is located on the side of the waveguide 1470 opposite to the side near the eye of a person. Light, which is emitted from the display panel 1472 and is incident upon the first diffraction grating 1474 at a predetermined incidence angle, is transmitted by the first diffraction grating 1474 in the left direction within the waveguide at a predetermined angle. The light transmitted into the waveguide 1470 is propagated in the left direction of the waveguide 1440 and then is incident upon

the second diffraction grating 1476, which is the conjugate of the first diffraction grating 1474, at the same angle as the transmission angle of the first diffraction grating 1474. The incident light is reflected by the second diffraction grating 1476 at the same angle as the incidence angle of the first diffraction grating 1474 toward the eye of a person. Magnifying glasses are located on the side of the waveguide 1470 which reflected light reaches, so that a user can view a magnified image of a video signal through the magnifying glasses. In this embodiment, the first diffraction grating 1474 is a transmission diffraction grating, and the second diffraction grating 1476 is a reflection diffraction grating.

As described above, it can be seen that various types of monocular wearable display systems can be realized depending on the arrangement of a display panel and diffraction gratings on the basis of a waveguide. Embodiments having the structures of the above-described embodiments in which light is propagated in the right direction can be further derived from the latter embodiments.

FIG. 15A shows a monocular wearable display system according to another embodiment of the present invention. In this embodiment, a display panel 1500 is located on the flank of one end of a waveguide 1504, and a first diffraction grating 1506 is parallel to the display panel 1500. A second diffraction grating 1510, which is the conjugate of the first diffraction grating 1506, is installed on the side of the waveguide 1504 opposite to the side near the eye of a person. Light of a video signal from the display panel 1500 is transmitted by the first diffraction grating 1506 and propagated into the waveguide at a predetermined angle. The transmitted light is incident upon the second diffraction grating 1510 at the same angle as the transmission angle. Light incident upon the second diffraction grating 1510 is reflected at the same angle as the incidence angle of the first diffraction gratings on the basis of the waveguide 1504 so that the reflected light heads for the eye of a person. A magnifying glass (not shown) such as an eyepiece is installed on the surface of the waveguide that the reflected light reaches, and magnifies an image. Here, the first diffraction grating 1506 is a transmission diffraction grating, and the second diffraction grating 1510 is a reflection diffraction grating.

FIG. 15B shows another embodiment of a monocular wearable display system which has the same structure as that of FIG. 15A but adopts different types

of diffraction gratings. Also, in this embodiment, a display panel 1520 is located on the flank of a waveguide 1524, and a first diffraction grating 1526 is parallel to the display panel 1520. A second diffraction grating 1530, which is the conjugate of the first diffraction grating 1526, is installed on the side of the waveguide 1524 near the eye of a person. Light of a video signal from the display panel 1520 is incident upon the first diffraction grating 1526 and transmitted thereby into the waveguide at a predetermined angle. The transmitted light is incident upon the second diffraction gratings 1530 at the same angle as the transmission angle. Light incident upon the second diffraction grating 1530 is transmitted at the same angle as the incidence angle of the first diffraction gratings on the basis of the waveguide 1524 so that the transmitted light heads for the eye of a person. A magnifying glass (not shown) is located on the surface of the waveguide that the reflected light reaches, and magnifies an image. Here, the first and second diffraction gratings 1526 and 1530 are transmission diffraction gratings.

FIGS. 15A and 15B refer to only the case where a display panel is installed at the left flank of a waveguide. However, the location of a display panel can be changed according to a designer's selection. In this case, a first refraction grating must not necessarily be located on the same side of the waveguide where a display panel is located.

A three-dimensional image can also be achieved by the use of two monocular wearable display systems as described above.

FIGS. 16A and 16B show aspects in which chromatic aberration is removed by diffraction gratings used in the present invention. Chromatic aberration is generated by the landing of R, G and B components of an incident color signal at different positions without being focused on one place. However, if a color signal is propagated via the refraction gratings used in the present invention, different color components R, G and B can be focused on one place by the combination of the above-described diffraction gratings having a conjugate relationship.

In FIG. 16A, both a first diffraction grating and a second (and a third) diffraction grating 1610 are transmission diffraction gratings, and the color components R, G and B of an incident signal are transmitted by the first diffraction grating 1600 at different transmission angles. Each of the transmitted color

components is incident upon the second diffraction grating 1610 at the same angle as the angle at which each of the color components is transmitted by the first diffraction grating 1600, and transmitted by the second diffraction grating 1610 at the same angle as the incidence angle of the first diffraction grating. The transmitted color components are incident in parallel upon a magnifying glass 1620 such as an eyepiece, and are focused on the same focal distance by the magnifying glass 1620, thus obtaining an image from which chromatic aberration is removed.

FIG. 16B refers to a case where a first diffraction grating 1630 and a second (third) diffraction grating 1640 are transmission diffraction gratings, and components R, G and B are incident upon the first diffraction grating 1630 at a predetermined incidence angle. The color components R, G and B incident upon the first diffraction grating 1630 at the predetermined incidence angle are propagated at the same transmission angle and incident upon the second diffraction grating 1640 at the same angle as the propagation angle. The incident color components are transmitted by the second diffraction grating 1640 at the same angle as the incidence angle of the first diffraction grating 1630, and are incident upon a magnifying glass 1650 such as an eyepiece in parallel. The magnifying glass 1650 allows the parallel incident color components to be focused on the same focal distance, thereby obtaining an image from which chromatic aberration is removed. The removal of chromatic aberration is achieved by the above-described diffraction gratings having a conjugate relationship.

The above-described wearable display systems can be manufactured by incorporating diffraction gratings into a waveguide, by incorporating an eyepiece into a waveguide, or by incorporating diffraction gratings and magnifying glasses into a waveguide.

The waveguide is made of glass or plastic, in particular, of acrylic matter (PMMA).

The magnifying glass can be made of an holographic optical element (HOE) or a diffraction optical element (DOE). The magnifying glass can be a diffraction lens, a refraction lens, a combination of a diffraction lens and a refraction lens, or an aspherical lens.

FIGS. 17A through 17C show types of diffraction gratings capable of being used in the present invention. FIG. 17A shows a binary diffraction grating which is spherical, and diffracts light in both directions. FIG. 17B shows a brazing diffraction grating which is saw-toothed, and diffracts light in only one direction. FIG. 17C shows a diffraction grating which is formed of multiple layers to increase the efficiency of diffraction of light. A hologram grating can also be used. These diffraction gratings can also be manufactured of an HOE or DOE.

FIGS. 18A through 18E show various types of ocular lenses.

FIGS. 19A through 19F show examples of multi-layered diffraction gratings.

According to the present invention, a wearable display system having a reduced weight and volume can be achieved by minimizing the number of optical components, and the complexity and cost for the manufacture of a display system can be reduced. Also, a waveguide, diffraction gratings and eyepieces can be incorporated in one body, and mass production of a display system is possible.

[Effect of the Invention]

A wearable display system according to the present invention uses a minimum number of optical devices, so that it is simply manufactured at a reduced cost, and the volume and weight of a display system are reduced. The use of diffraction gratings contributes to remove chromatic aberration.

FIG. 1

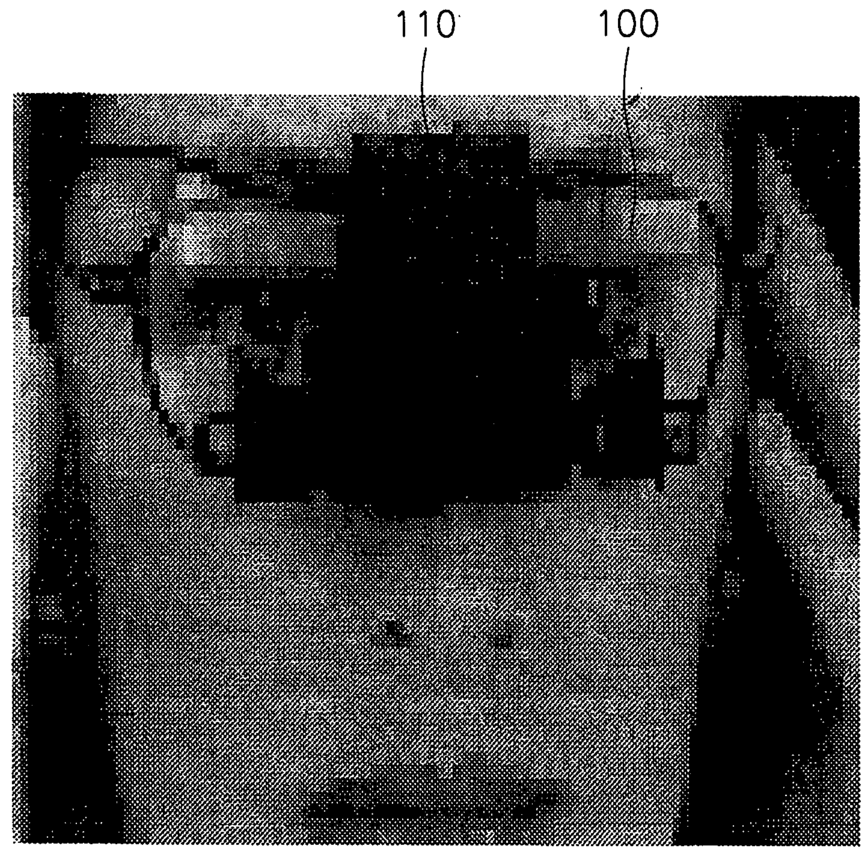

FIG. 2

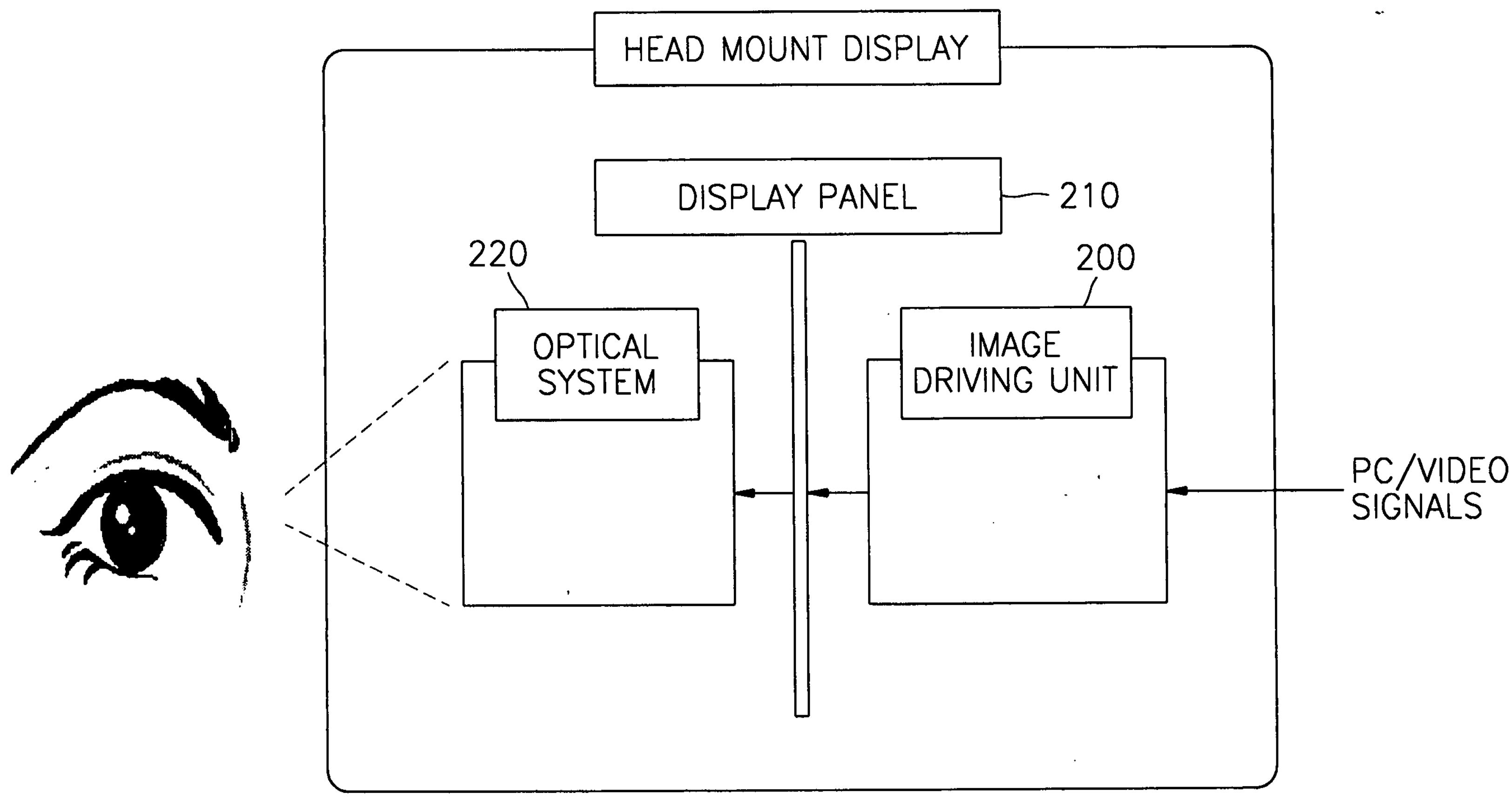
HEAD MOUNT DISPLAY
DISPLAY PANEL
210
220
OPTICAL SYSTEM
200
IMAGE DRIVING UNIT
PC/VIDEO SIGNALS

FIG. 3

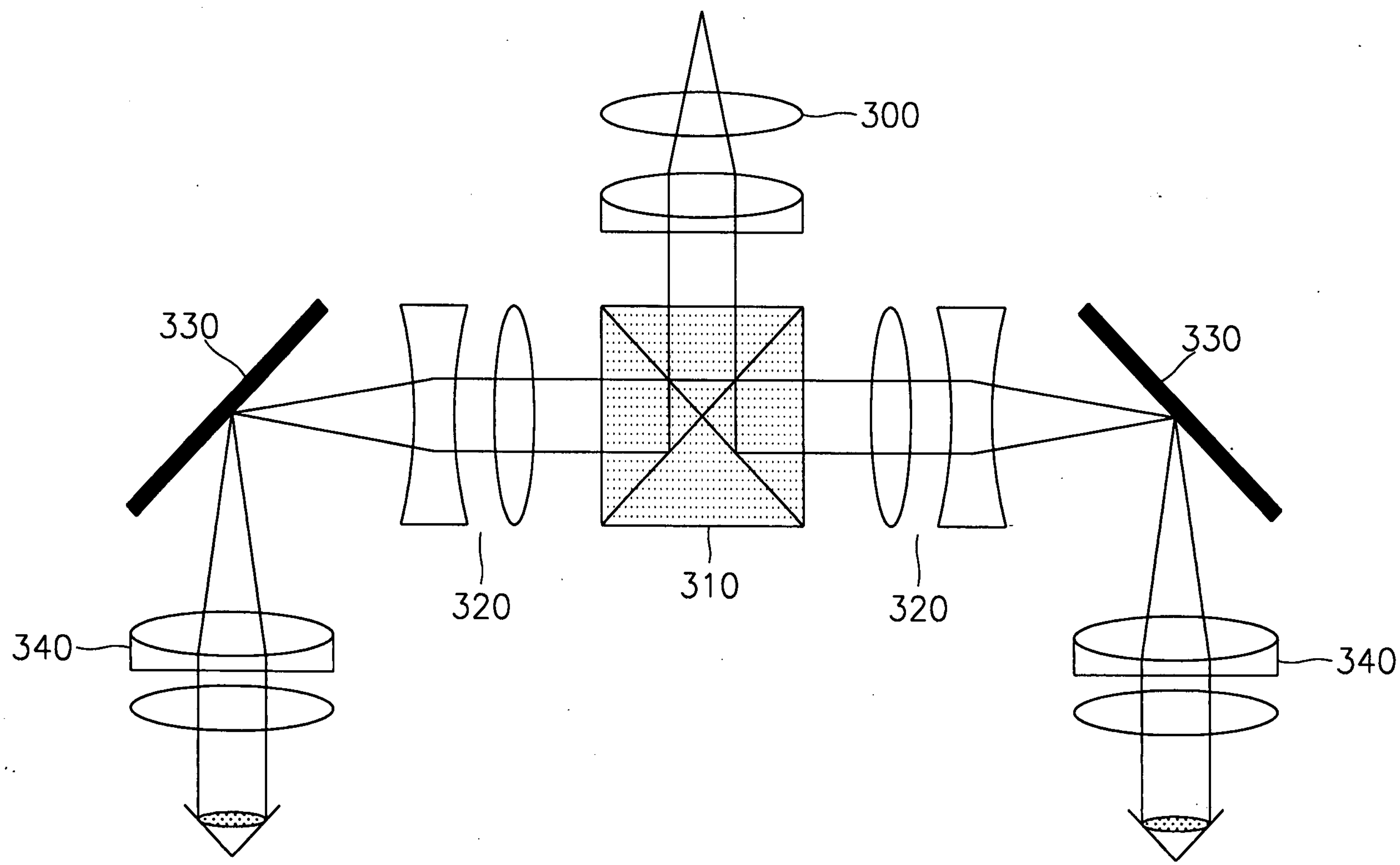

FIG. 4A

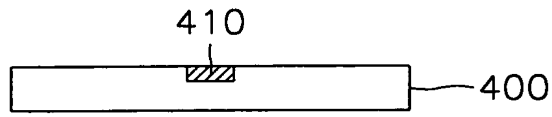

FIG. 4B

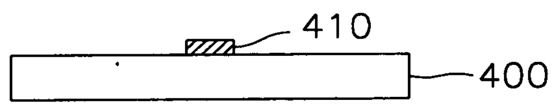

FIG. 5

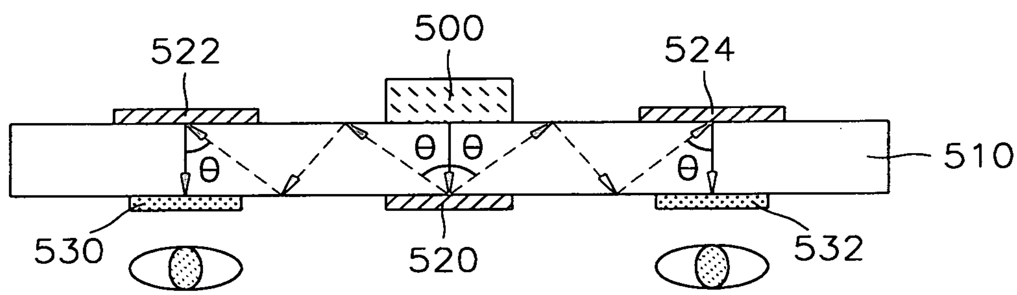

FIG. 6

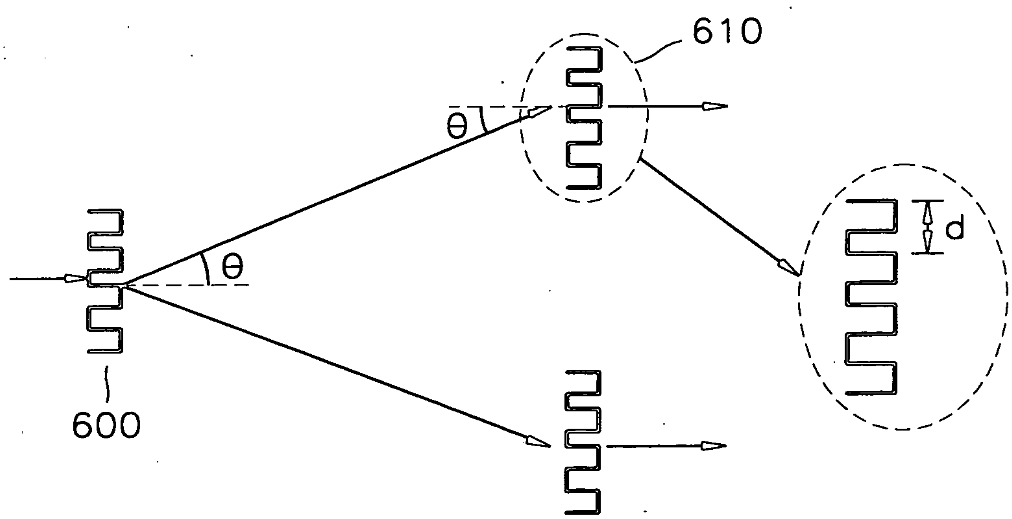

FIG. 7A

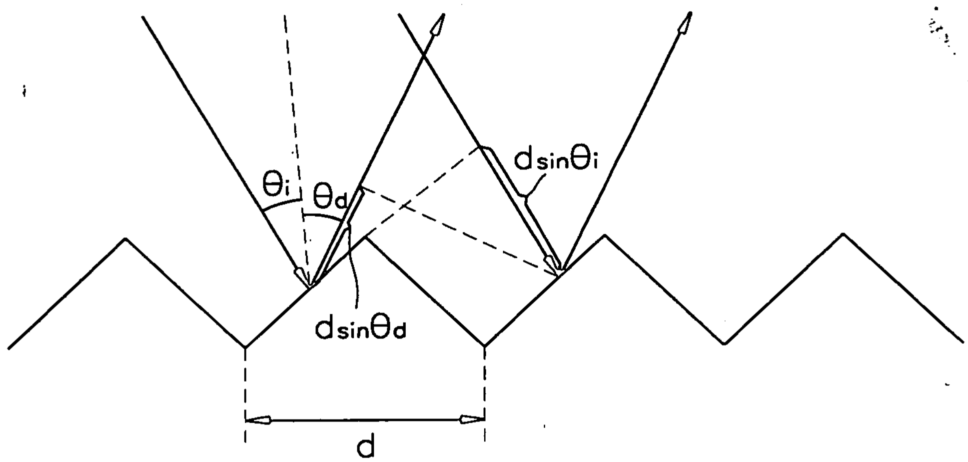

FIG. 7B

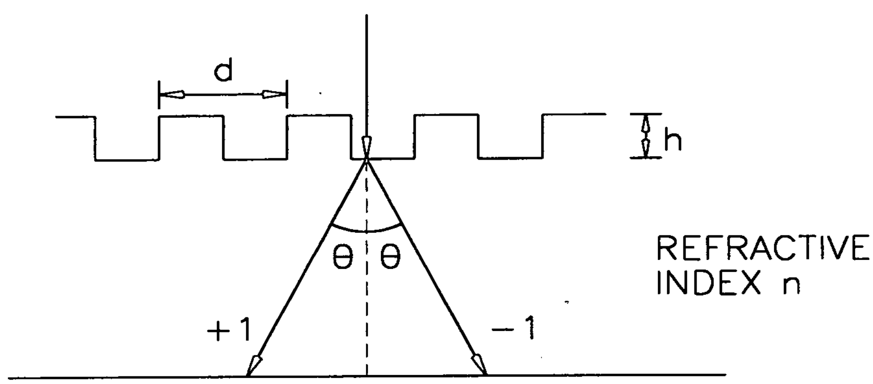

FIG. 7C

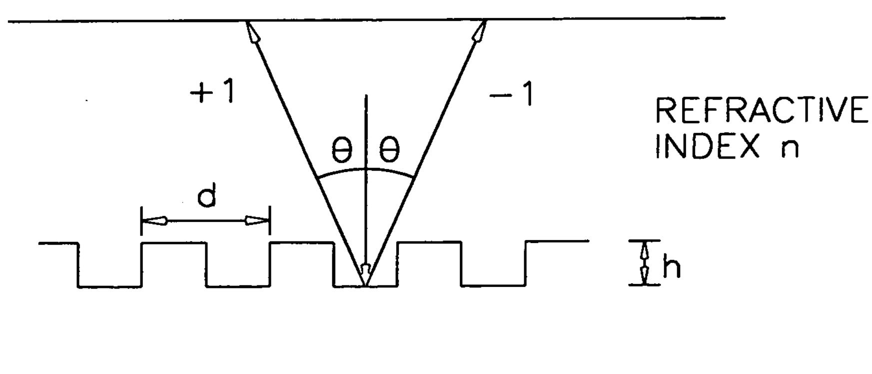

FIG. 8A

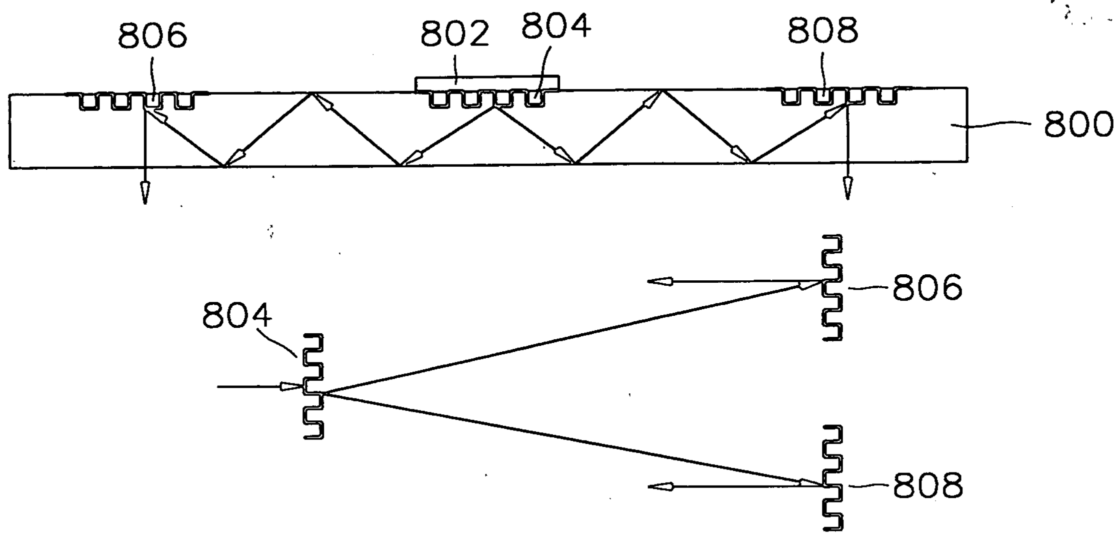

FIG. 8B

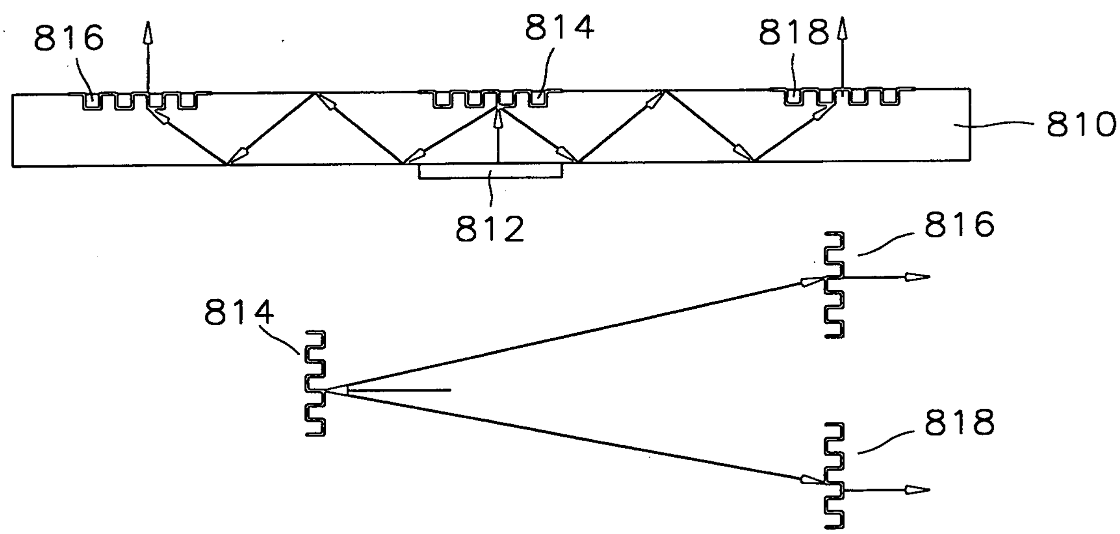

FIG. 8C

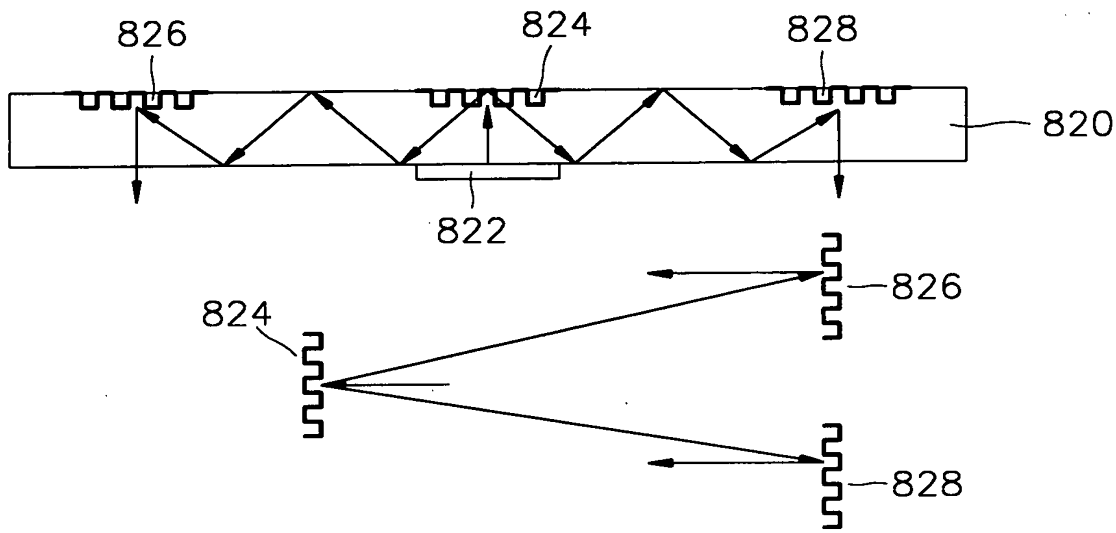

FIG. 8D

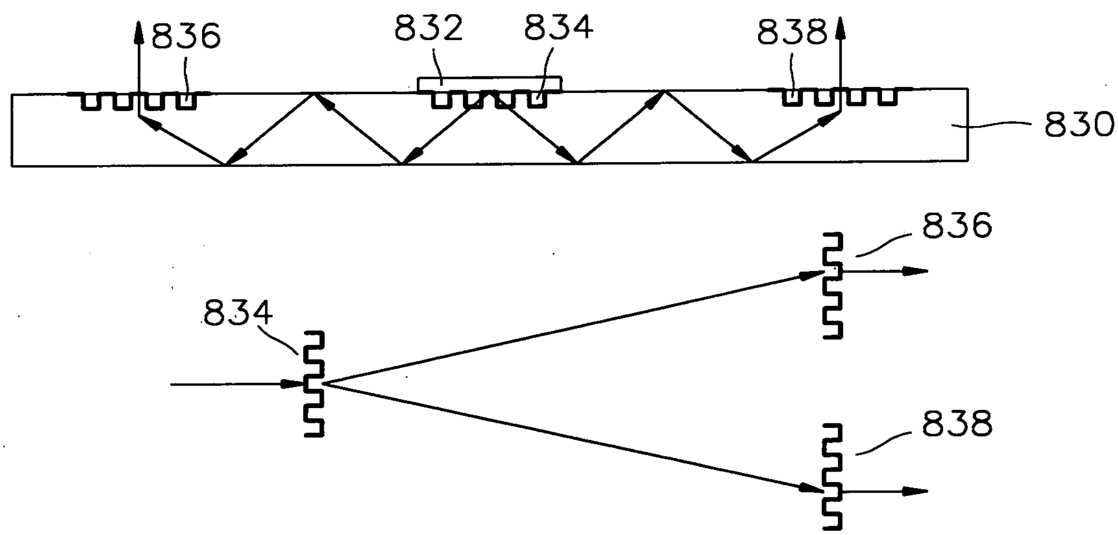

FIG. 8E

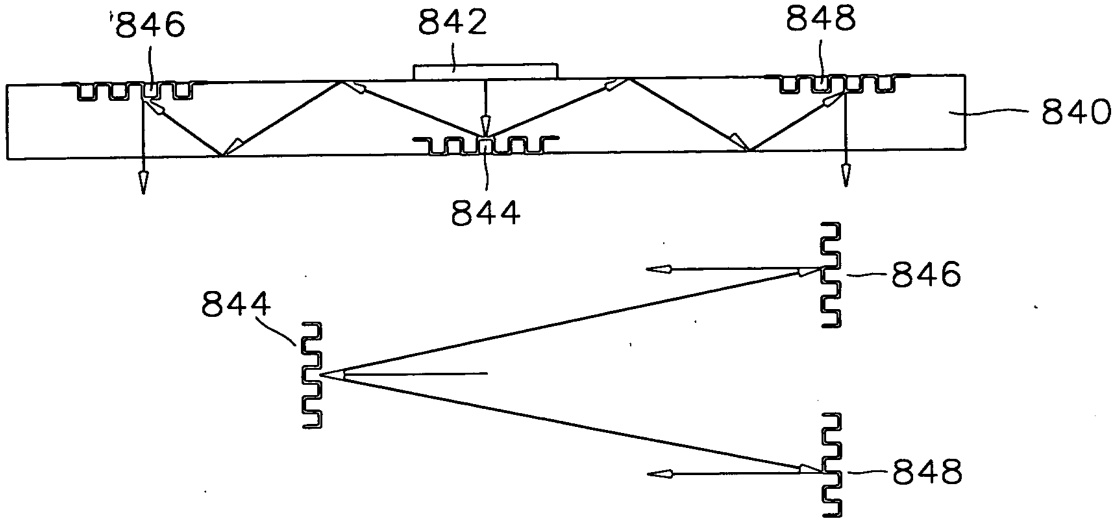

FIG. 8F

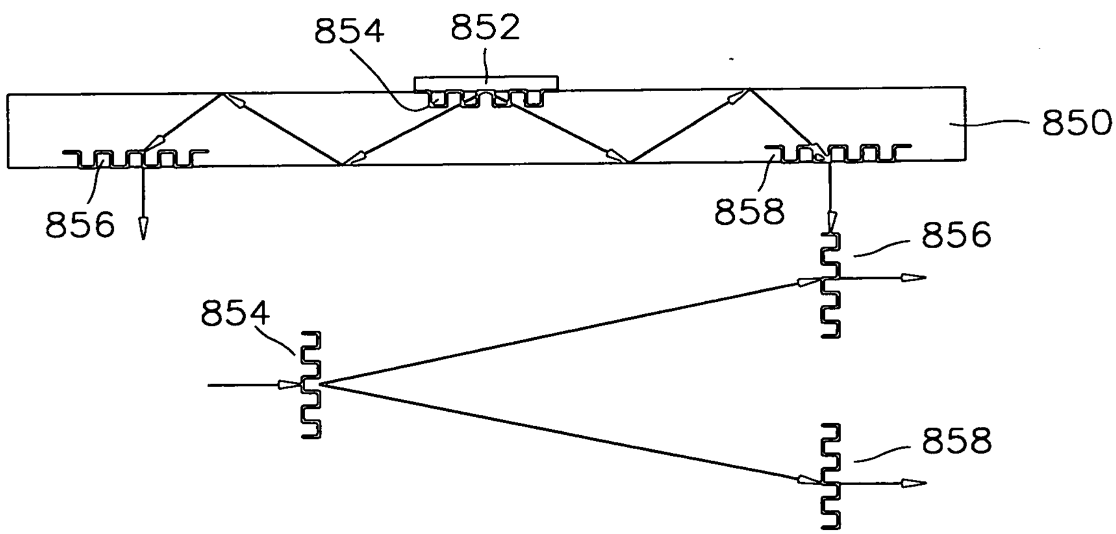

FIG. 8G

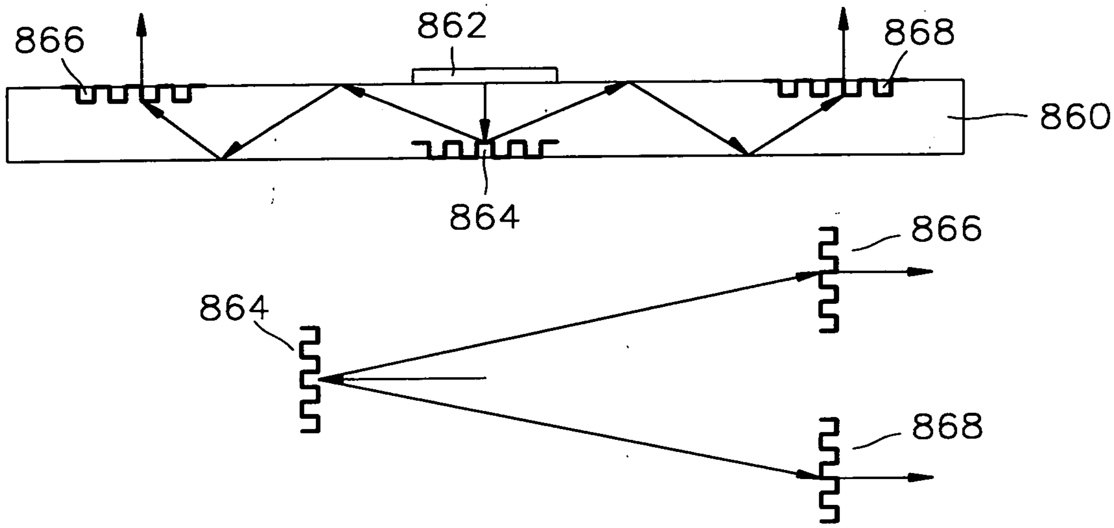

FIG. 8H

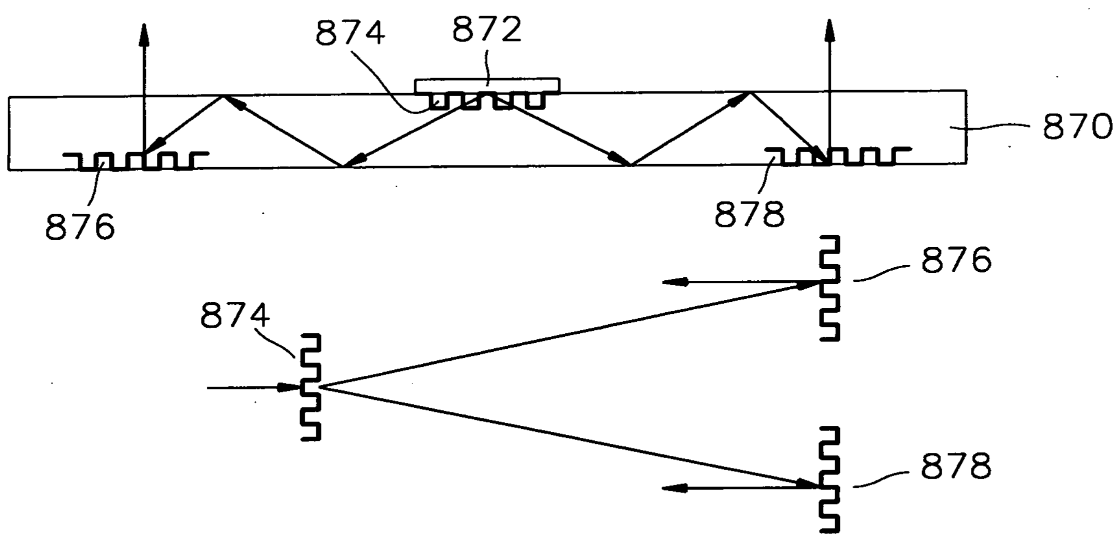

FIG. 9

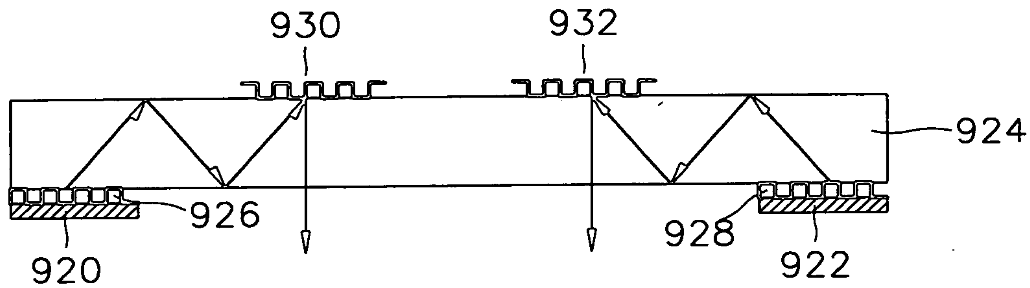

FIG. 10A

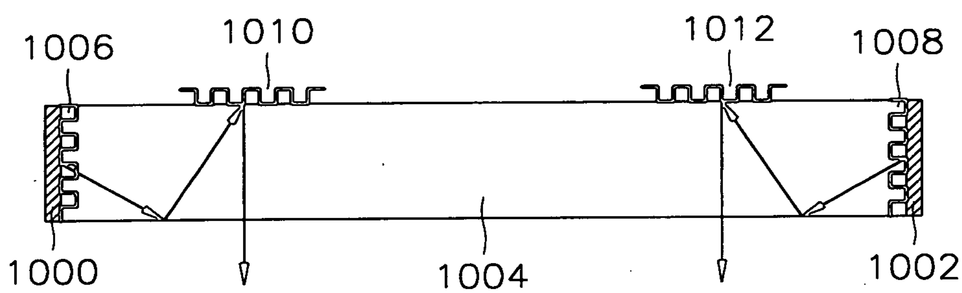

FIG. 10B

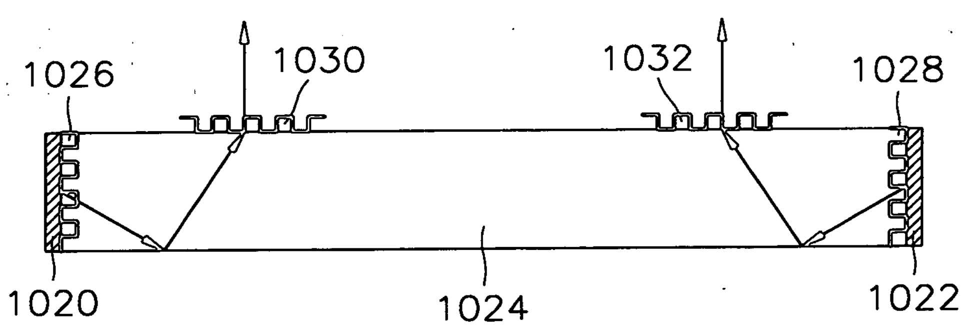

FIG. 11

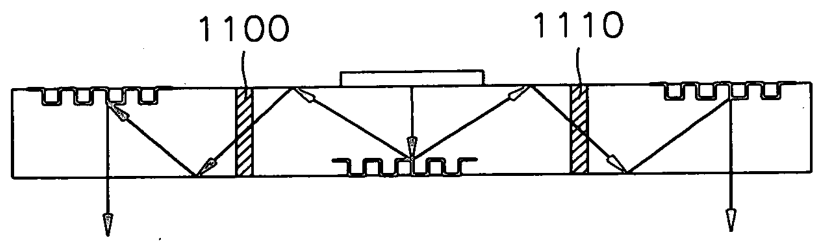

FIG. 12A

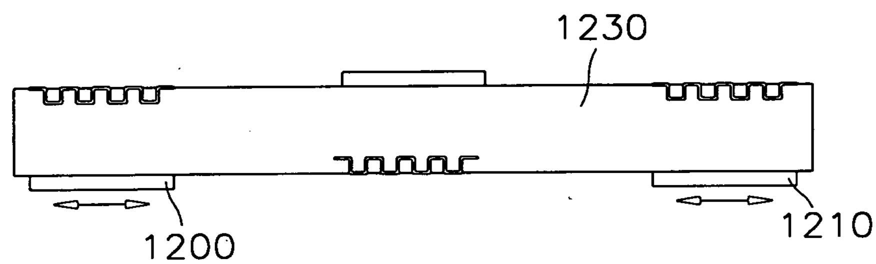

FIG. 12B

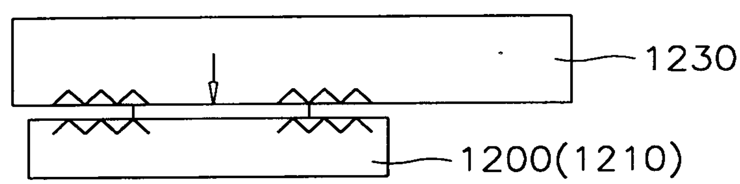

FIG. 13

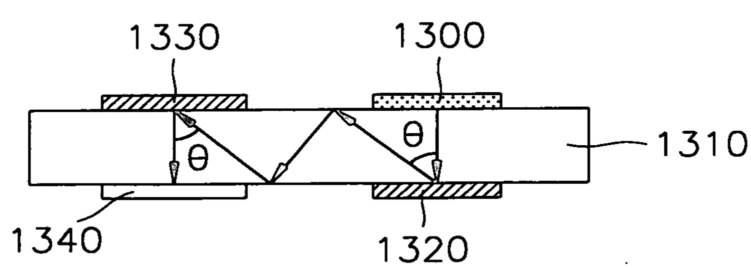

FIG. 14A

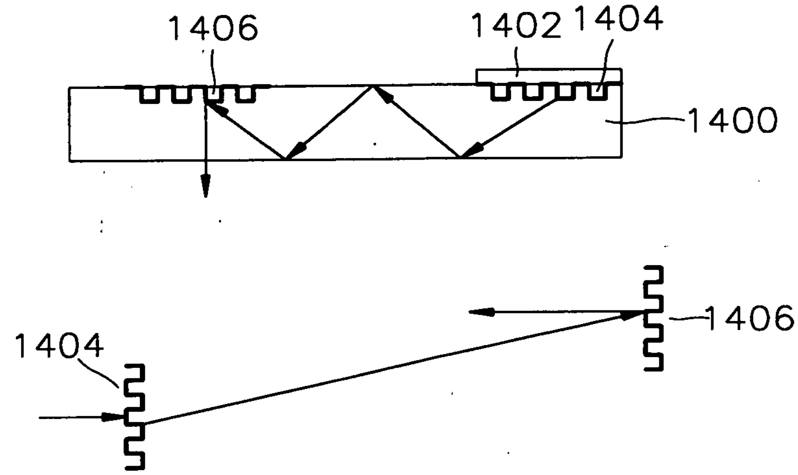

FIG. 14B

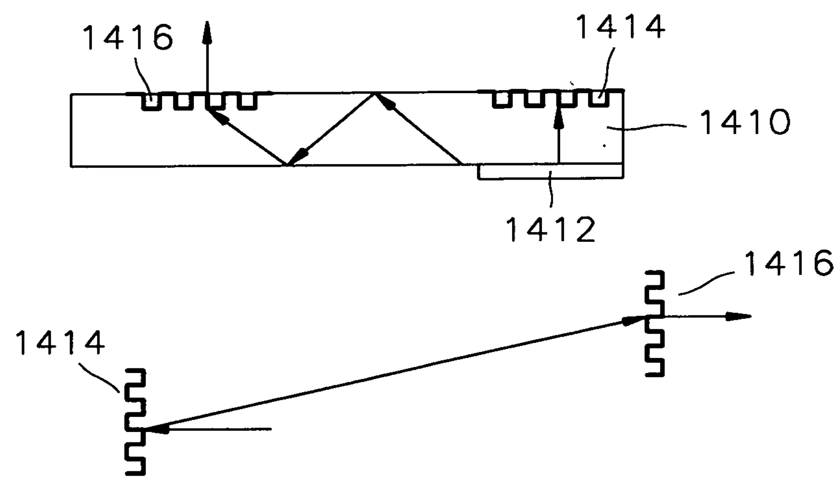

FIG. 14C

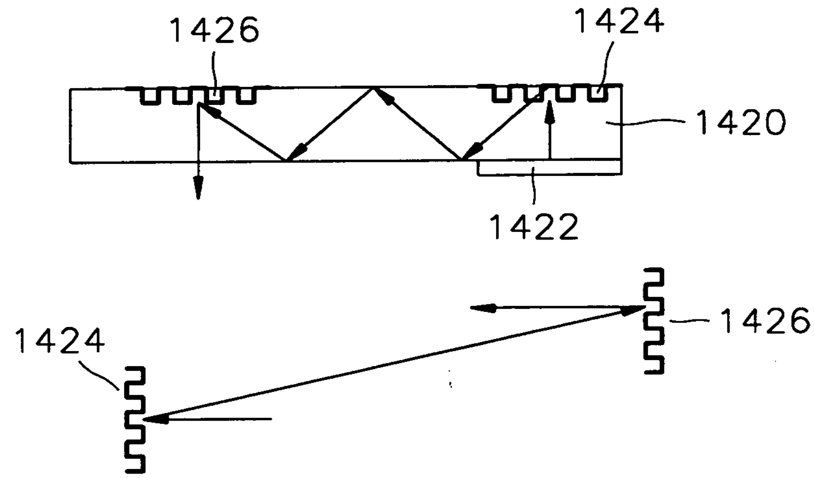

FIG. 14D

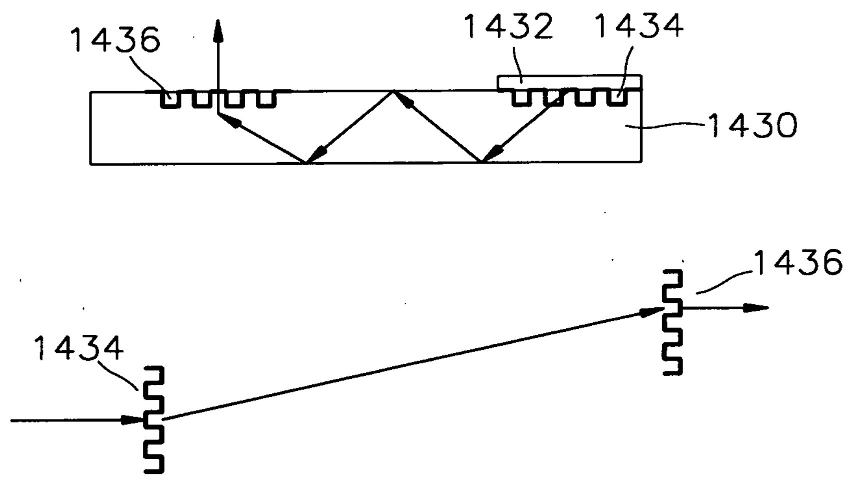

FIG. 14E

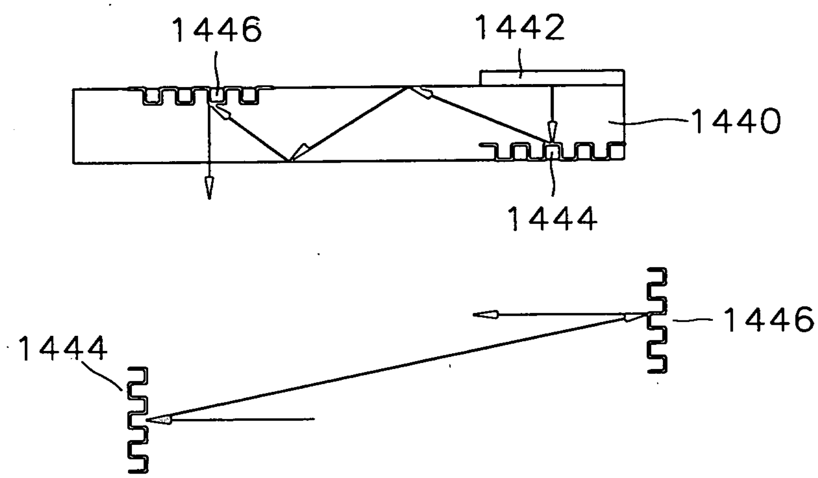

FIG. 14F

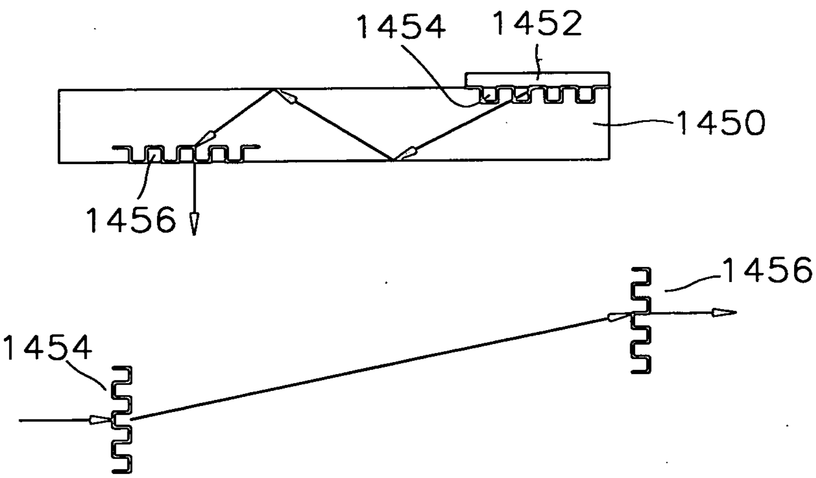

FIG. 14G

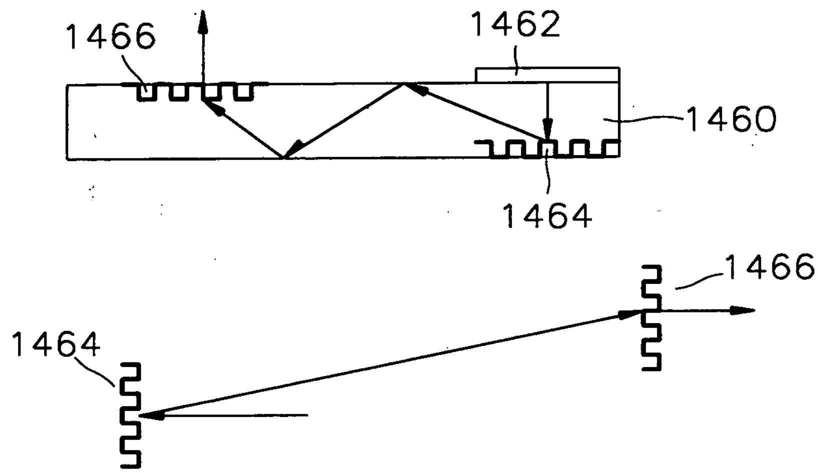

FIG. 14H

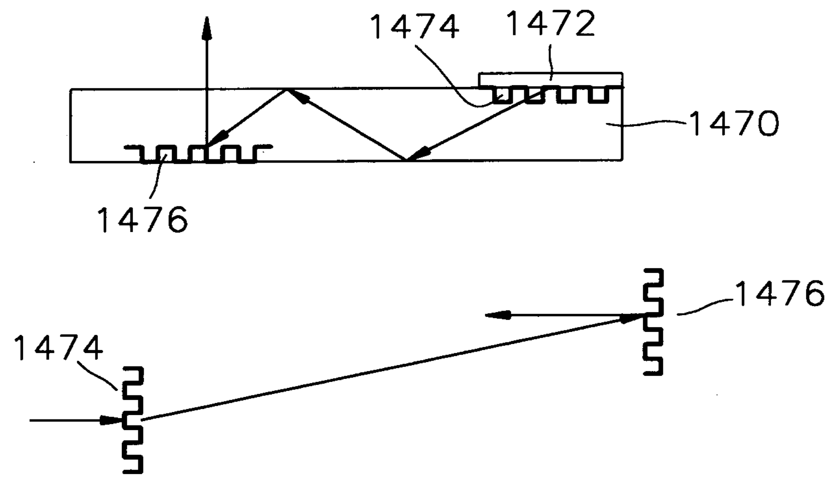

FIG. 15A

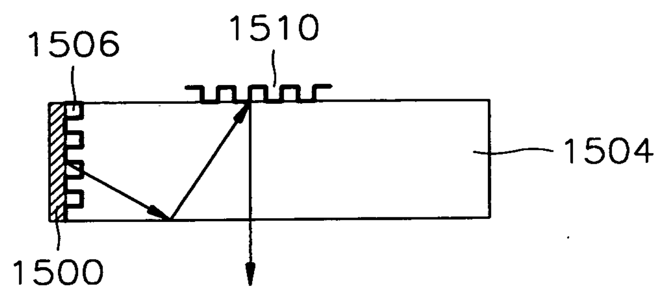

FIG. 15B

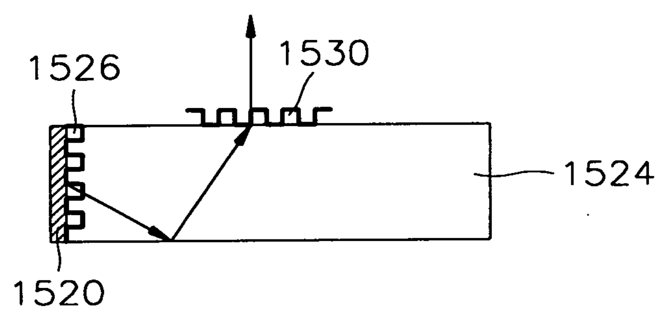

FIG. 16A

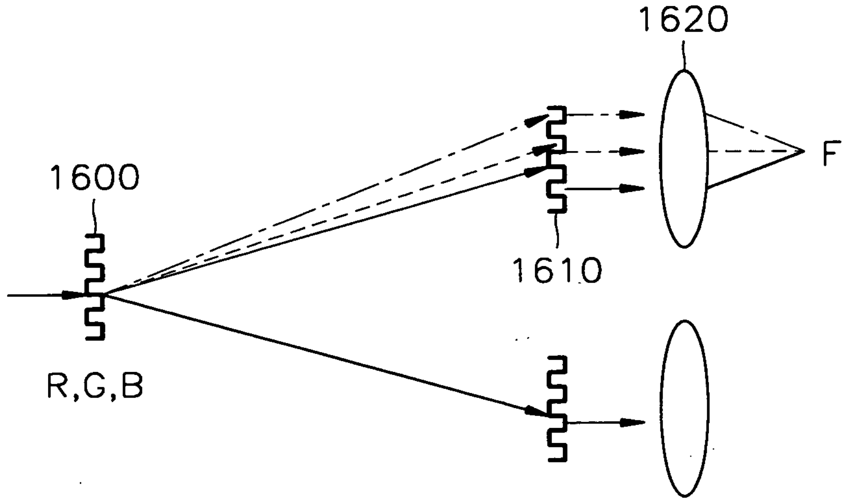

FIG. 16B

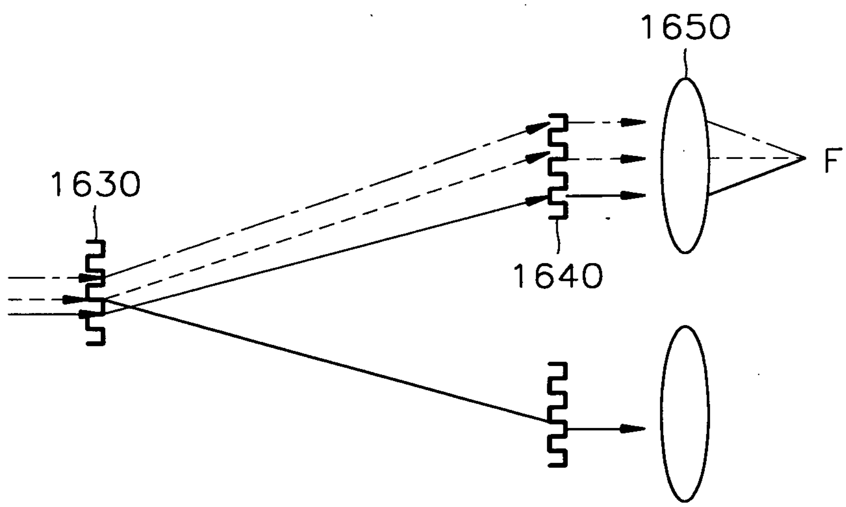

FIG. 17A

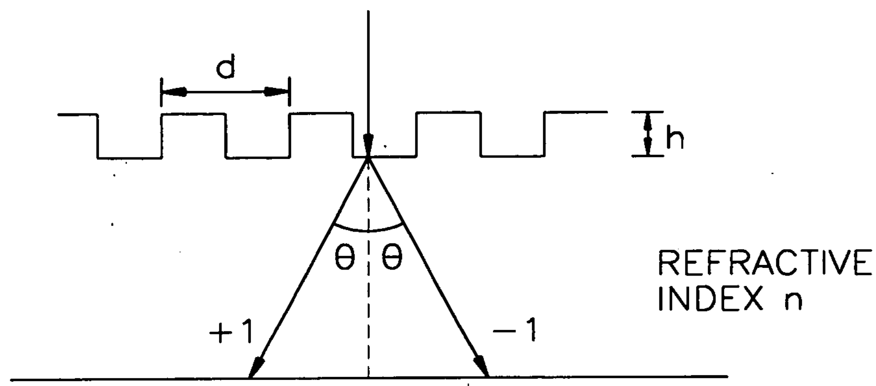

FIG. 17B

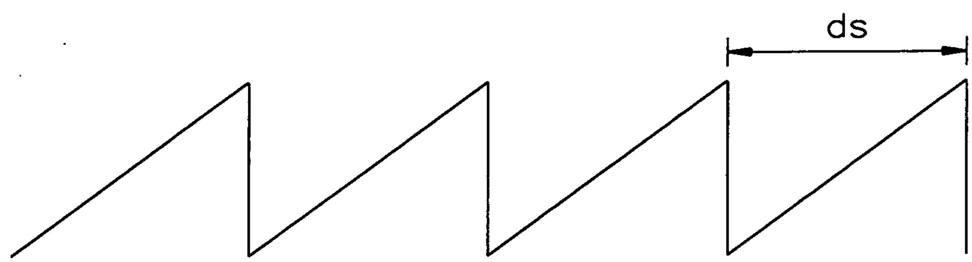

FIG. 17C

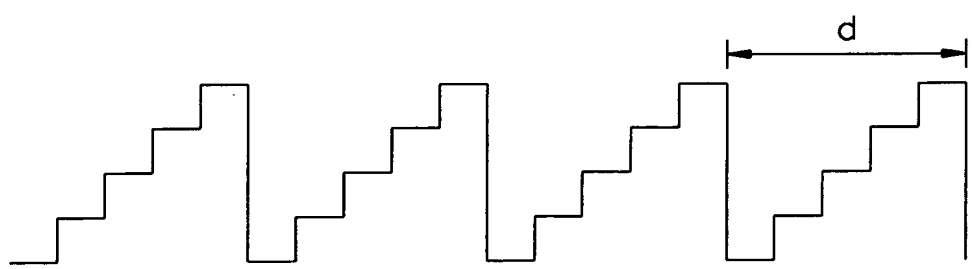

FIG. 18A

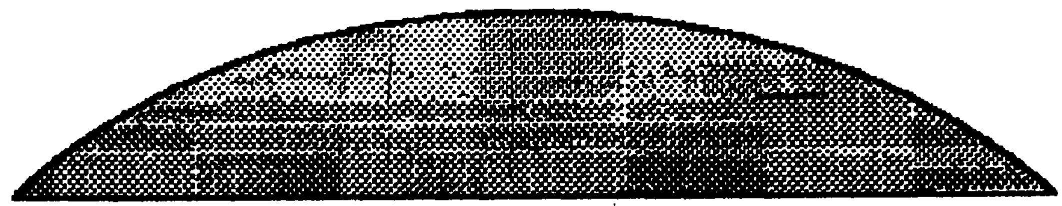

FIG. 18B

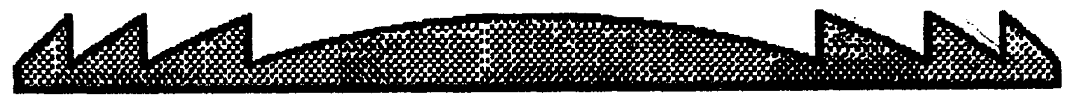

FIG. 18C

FIG. 18D

FIG. 18E

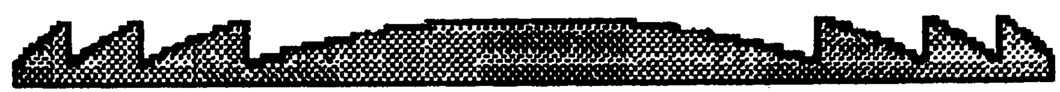

FIG. 19A

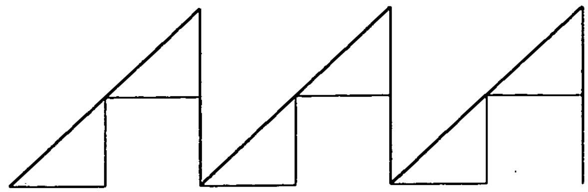

FIG. 19B

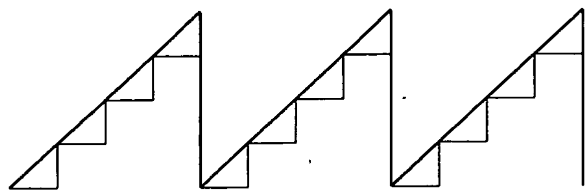

FIG. 19C

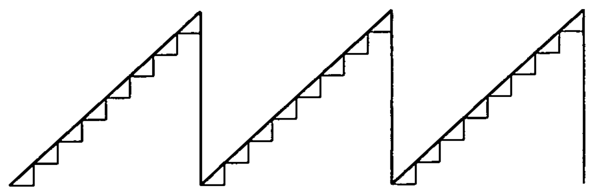

FIG. 19D

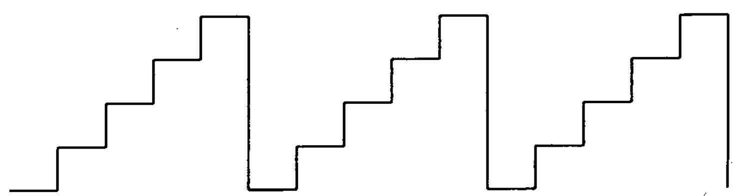

FIG. 19E

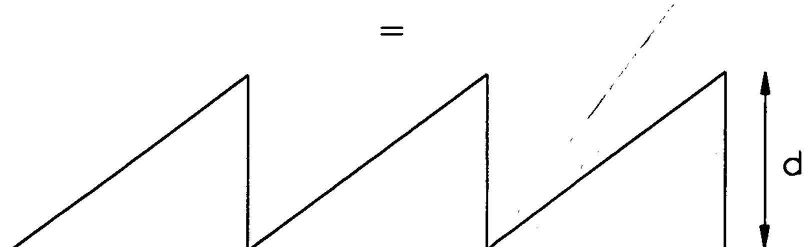

FIG. 19F